NBSIR 74-428

An Inspection Procedure for Detecting Hazardous Edges

John R. Sorrells, Robert E. Berger

Measurement Engineering Division
Consumer Product Systems Section
National Bureau of Standards
Washington, D. C. 20234

April 1974

Prepared for
Consumer Product Safety Commission
, Maryland 20016

NBSIR 74-428

AN INSPECTION PROCEDURE FOR DETECTING HAZARDOUS EDGES

John R. Sorrells, Robert E. Berger

Measurement Engineering Division
Consumer Product Systems Section
National Bureau of Standards
Washington, D. C. 20234

April 1974

This is a progress report. The work is incomplete and continuing. Conclusions are not necessarily those that will be included in a final report.

Prepared for
Consumer Product Safety Commission
Bethesda, Maryland 20016

U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

Introduction

The establishment of safety criteria and test methods for categorizing the hazard potential of exposed edges on consumer products is a complex problem. For simplification, this investigation, as previous ones 1/&2/, will be limited to the consideration of a special type of loading mechanism, which has come to be known as the "casual handling" injury mode. Under casual handling conditions, there is a normal force between the skin+ and the edge, a relative velocity in the direction parallel to the edge, but no relative velocity in the normal direction (except as when cutting occurs). In particular, impact or fall-on conditions are not considered. This casual handling loading mechanism is studied for convenience in identifying relevant parameters and in measuring forces. This is not to imply that other loading mechanisms are less dangerous or should not be studied.

In an earlier report 1/, the concept of a safety criterion was discussed. It was indicated that values for two parameters must be chosen in order to set criteria for edge safety. These are:

1. A force, F, which is considered representative of the casual handling of products.
2. An injury level, measured by the percent depth of cut of the skin, D^+, which is considered tolerable.

+By "skin" is meant the two outer layers: epidermis and dermis.

Several guidelines were presented for choosing these values. Together, they constitute the safety criterion:

S(F, D*)

The Consumer Product Safety Commission has recently chosen two separate safety criteria 3/, depending on the accessibility of an edge. It was decided than an "exposed"[+] edge will be considered acceptable if it does not break through the epidermis of human skin when the normal force between the edge and the skin is 20 pounds (89.0 newtons). "No break through the epidermis" corresponds to the "no bleeding" level of the previous report 1/.[++] This safety criterion can be expressed as:

S_I (20 lb., no epidermal break through)

For edges which may be contacted inadvertently, the Commission has chosen a less conservative safety criterion: such an edge will be considered acceptable if it does not completely penetrate human skin when the normal force between the skin and the edge is 4 pounds (17.8 N). The previous report 1/ pointed out that skin could be completely penetrated in spots although the measured percent depth of cut was less than 100%. To be conservative, the complete penetration level was taken to be 80%, leading to the safety criterion:

S_{II} (4 lb., 80%)

[+] The arbitrariness, in deciding whether or not an edge is likely to be contacted by a user is intentional. Obviously, it will depend on the particular product considered - the way it is used and for whose use it is intended.

[++] Break through here means complete penetration of the epidermis into the papillary layer of the dermis, which contains capillary blood vessels.

The results of cutting tests on excised human skin, using a series of eleven test edges, have also been reported 1/. For a given safety criterion, these edges could be divided into "safe" and "hazardous" categories. For criterion S_{II}, only the sharpest edge of the test family was considered to be hazardous. This is shown clearly in Figure 1 (which is Figure 19 in the previous report). For a given edge, each symbol represents a cut on a separate skin specimen. The filled-in circles indicate that a measurable groove remained in the skin, although the epidermis was not broken. The geometry of the edges is summarized in Figure 2. For criterion S_I, all of the test edges were considered to be hazardous. I.e. at 20 pounds (89.0 N), breaks in the epidermis were found when even the dullest edges were used.

Although the above safety criteria had not been chosen at the time, methods of discriminating between safe and hazardous edges were investigated 1/. It was found that simple definitions of edge geometry were not adequate because microscopic irregularities could affect an edge's cutting capability. Thus, synthetic materials were sought which, at some fixed force, would be cut completely through by only those edges deemed hazardous by a particular safety criterion. Initially, it was hoped that a single material could be found that would classify the test edges in the same order of sharpness as human skin. Then this material could be used as a cut indicator to discriminate between safe and hazardous edges for a wide range of safety criteria. Unfortunately, in the scope of this initial study, this ideal material was not found, although several materials were found which could be used to satisfy S_{II}.

The loading mechanism used in the experiments on the synthetic materials was different than that used in cutting the excised skin specimens. The skin was mounted on a mandrel that was rotated past the edge (Figure 3b). When synthetic materials were used, the mandrel was wiped back and forth in the direction parallel to the edge (Figure 3c). In order to simulate the loading mechanism of the skin experiments, the Consumer Product Safety Commission requested a modification in the discrimination procedure using synthetic materials 3/.

The purpose of the present report, then, is to describe a method of discriminating between the safe and hazardous edges of safety criteria S_I and S_{II}. In addition, this report will describe a device which can be used to test the hazard potential of exposed edges.

Additional Skin Cutting Experiments

In the introduction, it was pointed out that the original test edges, A through K, (See Figure 2) were unable to provide a discrimination point[+] for safety criterion S_I. This is because all of the edges were hazardous; at 20 pounds all edges were capable of breaking the epidermis of human skin. Thus it became necessary to supplement the test family with duller edges until edges were found which would be called safe.

The two additional edges used are L and M, which are also described in Figure 2. As with edge K, the least sharp of the original edges, the new edges also have a 90° included angle, but

[+] In the previous report 1/, the term "discrimination point" was used as a means of distinguishing between the safe and hazardous edges of a given safety criterion (e.g. safe edges were said to fall below the discrimination point).

with larger edge radii. Cutting tests were made on the same apparatus and with the same procedure as in the previous report 1/ (see Figure 3b). The force was held constant at 20 pounds (89.0 N).

The results of these tests are shown in Figure 4. Ten different specimens were tested on each of the two additional edges. On only one specimen was the epidermis broken.+ In this case, the penetration into the dermis was not very significant. None of the epidermis of the other specimens were broken when edges L and M were used at 20 pounds (89.0 N). These data are plotted in graphical form in Figure 5 (which, except for edges L and M, is Figure 23 of the previous report 1/).

For a given safety criterion, it was the convention of the previous report to label an edge "safe" if the prescribed percent depth of cut (for that criterion) was exceeded on only one skin specimen.++ By this convention, edges L and M would be judged safe for criterion S_1.

It remains to find a procedure which will make the following discriminations among the test edges:

+Determination of breaks in the epidermis was by visual inspection. In a preliminary histological study 4/, some of these "grooves" were shown to have made slight penetration into the papillary layer of the dermis (uppermost dermal layer, containing minute capillaries).

++This convention was followed so that a particularly weak specimen would not form the basis of a safety standard for the bulk of the population. Besides, there appeared to be some evidence that regulations based on these tests would be conservative 1/.

For S_I:

discriminate edges L and M (safe) from all others; or

discriminate edge M (safe) from all others.[+]

For S_{II}:

discriminate edge A (hazardous) from all others

Selection of a Synthetic Cut Indicator

With a rotary testing device, such as suggested by the sponsor, the cutting action of an edge is somewhat different than with a wiping type of test. With the rotary test, the interaction occurs between a short segment of the edge and a relatively long segment of the test material, whereas with a wiping test, the opposite holds (see Figure 3).

The apparatus for the skin cutting experiments of the previous report 1/ was modified so that synthetic materials could be tested in a rotational mode. The wooden mandrel was replaced by a 3/8 inch (.95 cm) diameter aluminum mandrel which was inserted in the lathe chuck. Synthetic materials were secured on the mandrel, and then the test edges were brought into contact with the material at prescribed forces 1/. The mandrel was rotated through one revolution by turning the lathe by hand.

Materials were sought which would make any or all of the three discriminations listed above. A material was said to make a particular discrimination, at some given force, if only those edges

---

[+]The discrimination of only edge M from the rest would also satisfy S_I, and may be preferred over the above discrimination because it is more conservative.

labelled hazardous cut completely through the material. Those materials which appeared promising in the earlier "wiping" experiments 1/ were tested, along with many others. As expected, a consequence of changing to the rotary motion was that higher forces were required to completely penetrate a given material with a given edge. These experiments were considered preliminary in the sense that they would produce a suitable material for use with an inspection device. The precise force levels to be used in an inspection procedure would then be determined by more careful experiments on the device itself.

It was decided that, if available, a single material which could make all three discriminations would be preferred. This would simplify the inspection procedure - especially for consumer products having edges which are unlikely to be contacted, as well as exposed edges. Other criteria which should be met by the chosen material are:

1. The forces required for complete penetration of the material should not be too high; otherwise the inspection device would not be convenient for hand use. It was felt that five pounds (22.2 N) is a reasonable upper limit for the force to be used with the device.
2. The material should be very thin - preferably on the same order of thickness as the epidermis of human skin 5/. Then any protrusion above an edge, which is capable of breaking through the epidermis of human skin, will also be capable of cutting completely through the material.

3. The material should be easy to mount. Thus materials which are manufactured with adhesive backings will be preferred over those which are not (provided, of course, that the adhesive is applied uniformly (with controlled thickness and does not interfere with a materials ability to make discriminations).

Of all materials tested, several were found that made the necessary discriminations: these included some poly(vinyl chloride) and polyethylene foams and several poly(tetrafluoroethylene) tapes of varying thicknesses. Of these, only the poly(tetrafluorethylene) tape of .006 inch (.15 mm) total thickness, including a .003 inch (.075 mm) adhesive backing, met all of the previous requirements. Thus, this material was selected for further testing with the inspection device.

An Inspection Device

In this section, an inspection device, which can be used with the selected synthetic material to test edges associated with consumer products, will be described. Any such device should satisfy the following criteria.

1. It should be hand-held. Thus it can be brought to the product, avoiding awkward and time consuming mounting procedures.
2. It should be usable in any direction. This again avoids positioning the product. It also suggests the use of springs for setting forces so that the direction of gravity can be made irrelevant.

3. The diameter of the mandrel, upon which the synthetic material is mounted, should be sufficiently small so that tiny openings, which are large enough to accommodate a child's finger, can also be inspected.
4. It should be capable of making a single rotation (to prevent more than one pass over the same cut) at a constant speed of rotation (to avoid a subjective speed set by the inspector).
5. The force between the edge and the mandrel should be within tolerable limits, even when the mandrel is spinning. Any inertial loading which may be induced by the spinning should be minimized.
6. It should be easy to use.

A device which satisfies these criteria is shown schematically in Figure 6. A photograph of the device is shown in Figure 7. The mechanical subassembly of Figure 6a incorporates a motor driven test finger to obtain the desired rotary motion. A steel rod, 3/8 inch (.95 cm) in diameter is used as the test finger. This is coupled to the output shaft of a small, shaded-pole gear motor. The motor is mounted to a base plate to which is attached a bearing block that provides rigid support for the test finger. The three mutually perpendicular axes, x-x, y-y and z-z (considered attached to the subassembly) pass through the center of gravity of the subassembly.

The 1/70 HP (0.107 W) motor provides an output shaft speed of 50 RPM (corresponding to a linear velocity of 1 inch per second (2.54 cm/s) at the surface of the test finger) and contains an

integral brake which automatically stops the output shaft within 5 degrees of rotation after removal of power. This is an important feature because it becomes possible to maintain a nearly constant rotational speed of the finger for the entire revolution. To stop the test finger after one revolution, a single lobed cam is mounted on the motor shaft. This cam operates an electrical switch which opens the motor circuit when activated.

The subassembly described above is connected to the main support unit, shown in Figure 6b, at the points "A"; i.e., the motor subassembly is allowed to rotate within the main support unit about the x-x axis. The support unit consists of a reference plate to which is attached a handle, two bearing support plates, and a subassembly for adjusting spring tensions.

To provide prescribed contact forces between the test finger and an edge, two identical springs on either side of the motor subassembly are connected to the support unit. On the motor subassembly, the springs are connected at the points marked "C" in Figure 6a. The line AC is parallel to the y-y axis. The springs are attached to the points "B" on the support unit. The line BB is parallel to the x-x axis.

To operate the assembled device, the selected synthetic material is applied to the test finger. The device is brought into contact with an edge at a nominal test position which is 1/4 inch (0.6 cm) from the tip of test finger (point "E" in Figure 6a). The operator positions the device until the z-z axis is parallel to the plane containing the reference plate of the

support unit (the shaded surface S in Figure 6b). An indicator is provided to insure that this lining-up procedure can be effected within prescribed limits. Stops are provided so that the angle through which the motor subassembly can rotate is limited to about 5 degrees (0.1 rad, corresponding to an arc length of about 1/2 inch (1.3 cm) for the tip of the finger).

The force between the edge on the test finger can be controlled by extending or shortening the springs. This is accomplished by turning a screw (at W in Figure 6b). A scale is provided to note prescribed force settings. The forces have been calibrated with an Instron testing machine. If the subassembly is off its stops, and if the edge is within 1/4 inch (0.6 cm) of the nominal test position, the error in setting the contact force is no greater than 5%.

Once the force is set, it remains for the operator to depress a switch (at H in Figure 6b) which closes the motor circuit and initiates the single-revolution cutting cycle. Because of the tolerance allowed in positioning the edge on the test finger, several parallel cuts can be made without replacing the synthetic material. The material is then peeled off of the test finger and visually inspected to see if it has been completely penetrated by the edge.

Tests with the Inspection Device

A roll of the selected poly(tetrafluoroethylene) tape was tested on the inspection device to find the force settings at which the appropriate discriminations (page 6) could be made. For

a given edge, the force required to cut through the material was sought. Each edge-force combination was tested many times so that any non-uniformities in the material would have been detected. Generally there was a range of forces in which accurate predictions of complete penetration could not be made. For example, edge M would cut through the material at 3.9 lb. (17.3 N) and above, and would not cut through at 3.5 lb. (15.6 N) and below. Between these forces, both cuts and no-cuts were recorded. From this data a force range could be determined for making each of the edge discriminations. This is shown in Figure 8. F_{HIGH} and F_{LOW} are the highest and lowest forces at which a particular discrimination could be made (within 0.1 lb., or 0.4 N). The recommended force settings are chosen near F_{HIGH} in the interest of safety.

It was qualitatively determined that the mechanical strength of the adhesive backing is negligible compared to that of the poly(tetrafluoroethylene) film. Thus the accuracy in determining the forces required to cut through the material is probably limited by the tolerance in specifying the thickness of the poly(tetrafluoroethylene) film, i.e., .003 $\pm$ .0005 inch (.076 $\pm$ .013 mm) or $\pm$ 17%. Variations in thickness within a single roll are probably reflected in the force range reported above (on the order of $\pm$ 5%). Variations from roll to roll may be even larger. This conjecture was confirmed in some preliminary testing of three samples from separate production batches with average poly(tetrafluoroethylene) film thicknesses of .0028, .0031 and .0033 inches (.071, .079, .084 mm). Corresponding shifts in F_{HIGH} and F_{LOW} were indicated, but there was insufficient

material for accurate determinations. Even with these relatively large variations in thickness, the "hazardous" edges for criterion S_1 always cut the tape at the recommended force setting.

The manufacture of this poly(tetrafluoroethylene) tape to stricter tolerances may be a worthwhile endeavor for the future. For the present, the need for a safety standard on edges may preclude possible problems associated with tape variability - especially in light of the fact that the variability in skin is even larger 1/. In fact, this latter source of variability may well overshadow all others.

Summary

The device described in section IV can be used to test edges which are associated with consumer products. The .006 inch (.15 mm) poly(tetrafluoroethylene) tape, which satisfies all criteria for cut indicators (page 7), has been selected as the recommended synthetic material to be used in the inspection procedure.

At a contact force of 3.8 pounds (16.9 N), this material is completely penetrated by only those test edges which are capable of breaking through the epidermis of human skin+ when the contact force is 20 pounds (89.0 N). This satisfies safety criterion S_1. for exposed edges on consumer products.

At a contact force of 1.1 pounds (4.9 N), this material is completely penetrated by only those test edges which are capable of completely penetrating human skin when the contact force is

+I.e. excised abdomen skin, which is all that was available for the skin cutting experiments.

4 lbs. (17.8 N). This satisfies safety criterion S_{11}, for edges that would be contacted inadvertently.

The device described in this report is suggested as a feasible means of combining all the criteria for rotary device (page 8) into a workable model. It should be re-emphasized that this is a first-try prototype model, and it is expected that a finished product will benefit by many improvements.

It seems appropriate to restate some of the limitations mentioned in the previous report 1/. First of all, a regulation based on the prescribed safety criteria will protect against the stated injuries provided that the loading mechanism is of the "casual handling" mode. It is possible that such a regulation will protect against minor impacts, but this must be verified by experiment.

Secondly, the difference between cutting excised abdomen skin and cutting other areas of the body (which are more likely to be contacted by edges on consumer products) is unknown. It was suspected 1/ that regulations, based on the results of the skin cutting experiments, would be conservative. A program is currently underway to verify this conjecture, and to establish what safety factors may be in effect.

References

1. Sorrells, J.R. and Berger, R.E., "Some Cutting Experiments on Human Skin and Synthetic Materials," National Bureau of Standards Report NBSIR73-262 (October 1973)

2. McGuire, B.J., Sorrells, J.R. and Moore, J.D., "Resistance of Human Skin to Puncture and Laceration," National Bureau of Standards Report NBSIR73-123 (February 1973)

3. Armstrong, R.W., Bureau of Engineering Sciences, Consumer Product Safety Commission, personal communication (1973)

4. Deck, J,D., "Histology of Skin Cuts Made by Selected Edges," unpublished, personal communication, University of Virginia School of Medicine (1973)

5. Whitton, J.T., 'New Values for Epidermal Thickness and their Importance," Health Physics, 24, 1-8 (1973)

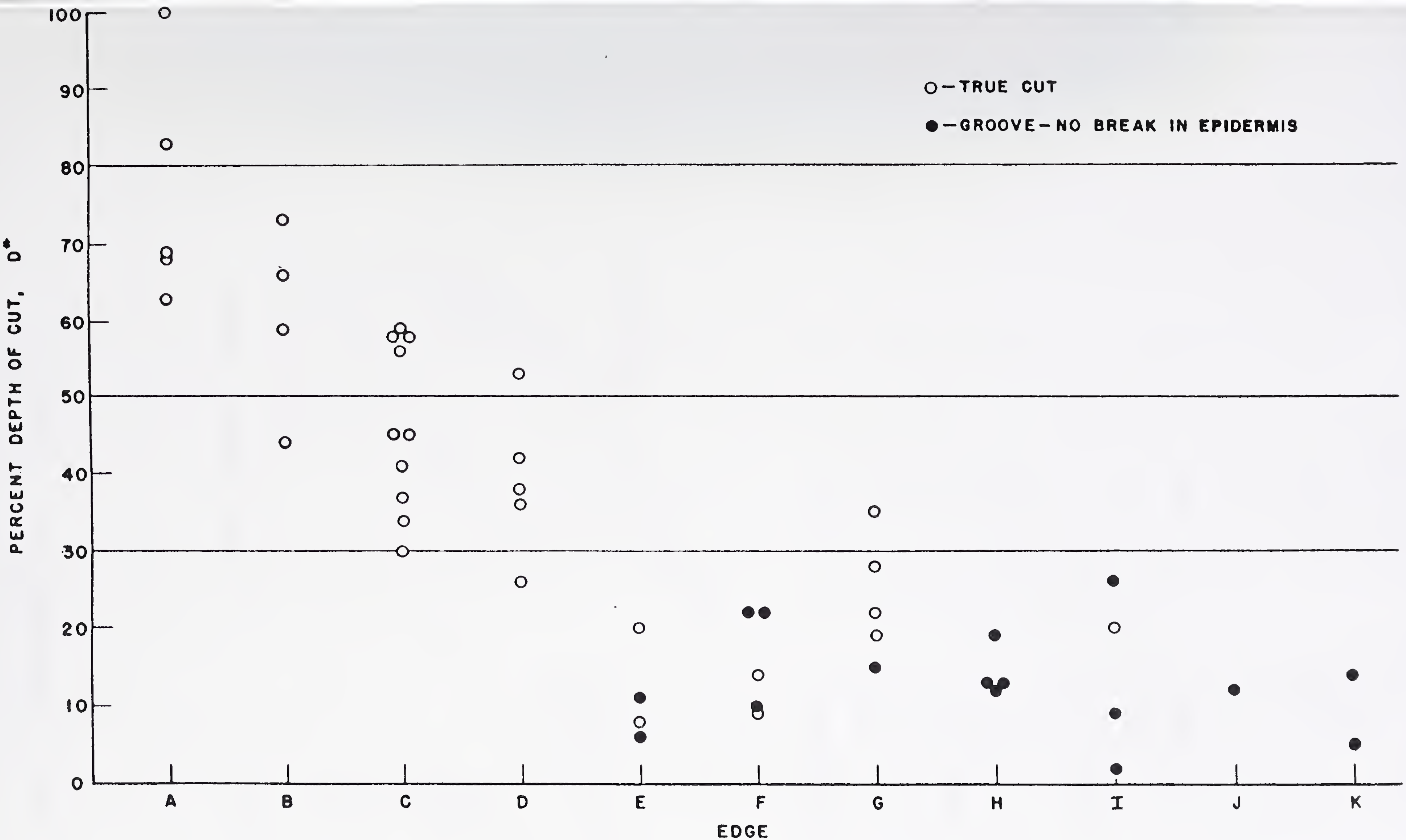


FIGURE 1. HUMAN SKIN CUT DATA FOR ALL TEST EDGES AT 4 POUNDS (17.8 NEWTONS)

	degrees, radians		
A	60°, π/3	.000"	GROUND
B	90°, π/2	.000"	GROUND
C	—	—	SHEARED
D	—	—	SHEARED
E	105°, 7π/12	.000"	GROUND
F	90°	.000"	GROUND
G	15°, π/12	.002" (.05 mm)	GROUND
H	30°, π/6	.002"	GROUND
I	60°	.002"	GROUND
J	15°	.004" (.10 mm)	GROUND
K	90°	.002"	GROUND
L	90°	.004"	GROUND
M	90°	.008" (.20mm)	GROUND

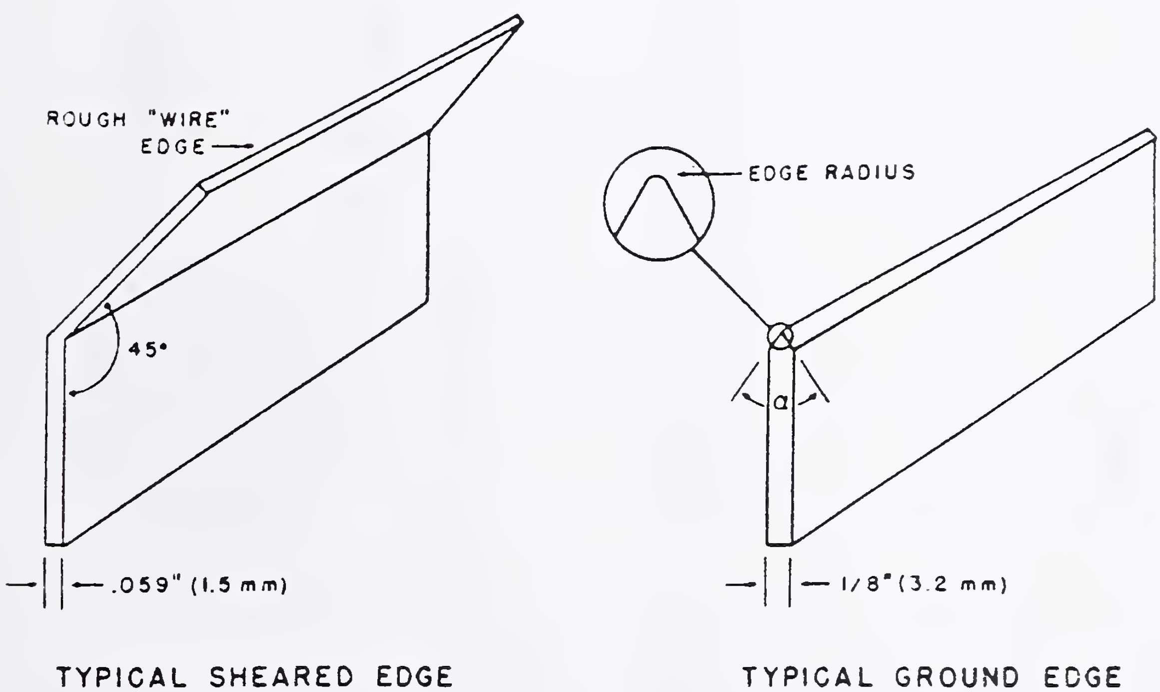


FIGURE 2. DESCRIPTION OF TEST EDGES

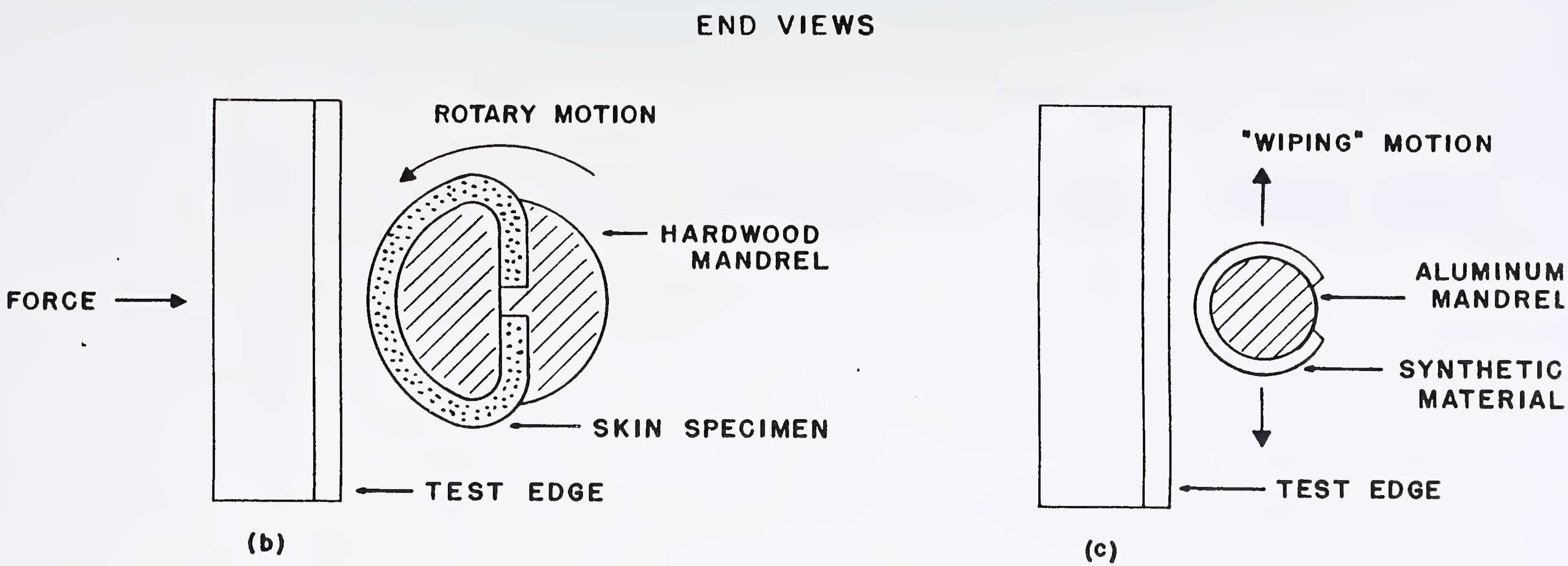


FIGURE 3. SCHEMATIC ILLUSTRATION OF CUTTING EXPERIMENT

Figure 4. Results of Skin Cutting Experiments for Edges L and M at 20 pounds (89.0 N)

Specimen Number	Age (years)	Sex	Average Thickness of Epidermis and Dermis (mm)	Test Delay (days)	Percent Depth of Cut*	
					Edge L	Edge M
34	45	F	1.2	4	28	6
35	27	M	0.9	2	24+	14+
37	55	M	1.3	4	6	5
38	38	M	1.9	2	25	22
39	27	M	1.3	2	24	27
40	74	F	1.2	4	26	26
41	5	F	0.8	3	40	29
42	35	M	2.0	1	27	23
49	59	M	1.4	8	19	20
50	49	M	1.6	5	16	8

+ This column is really the percent depth of the permanent groove left in the skin. Only for specimen 35 was the epidermis broken.

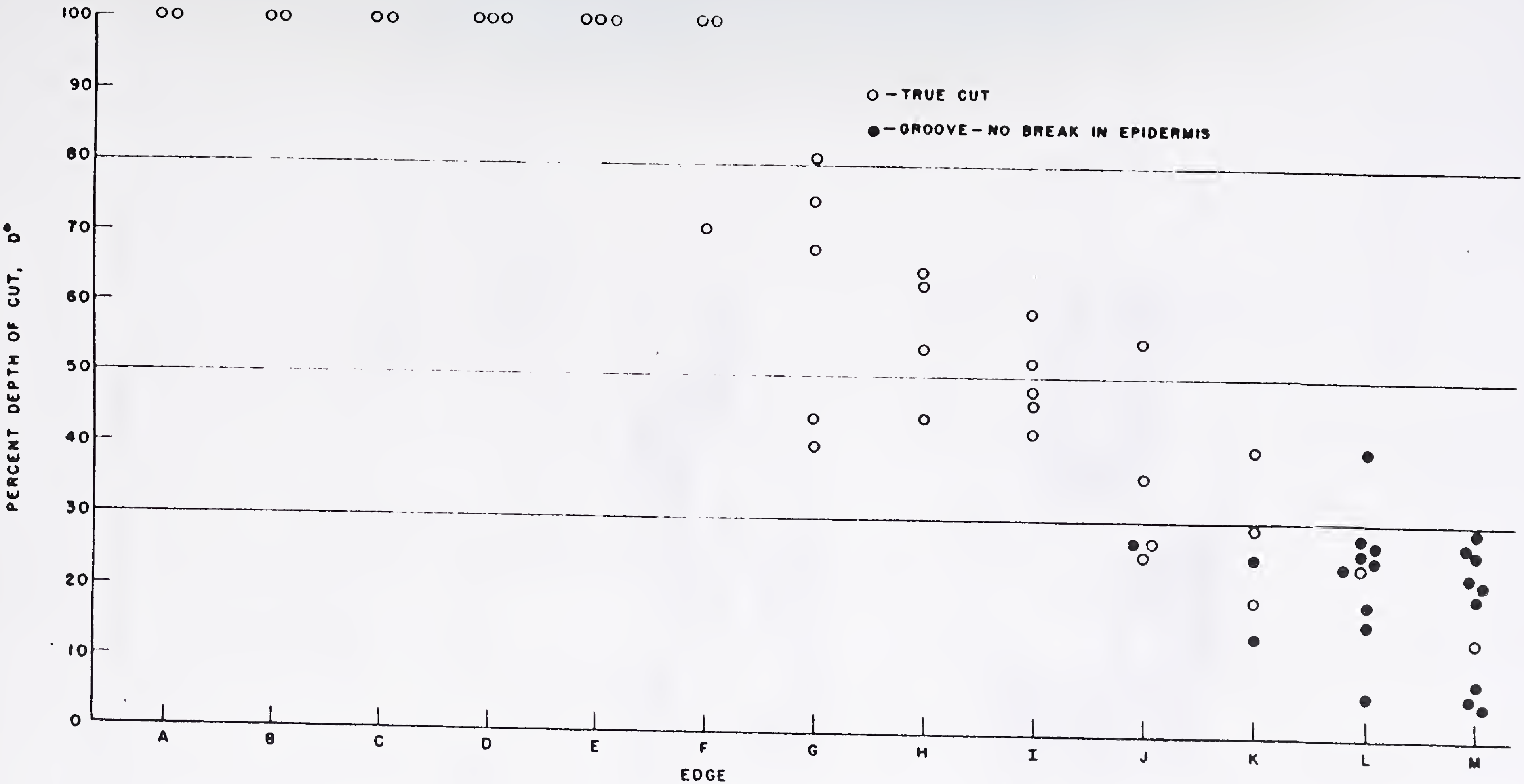
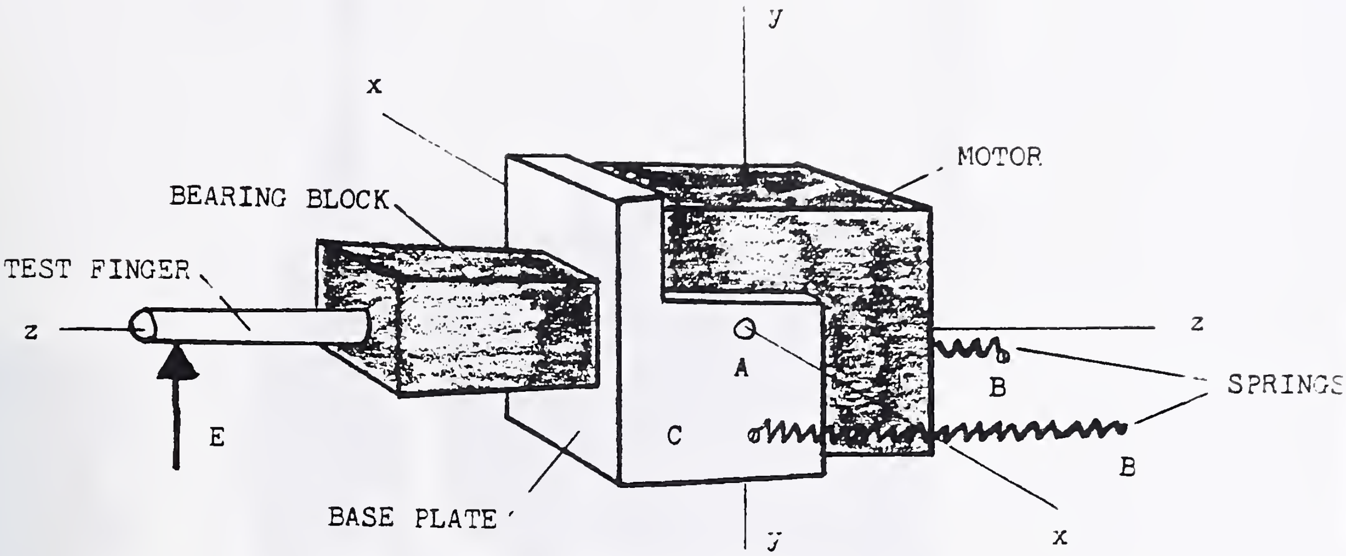
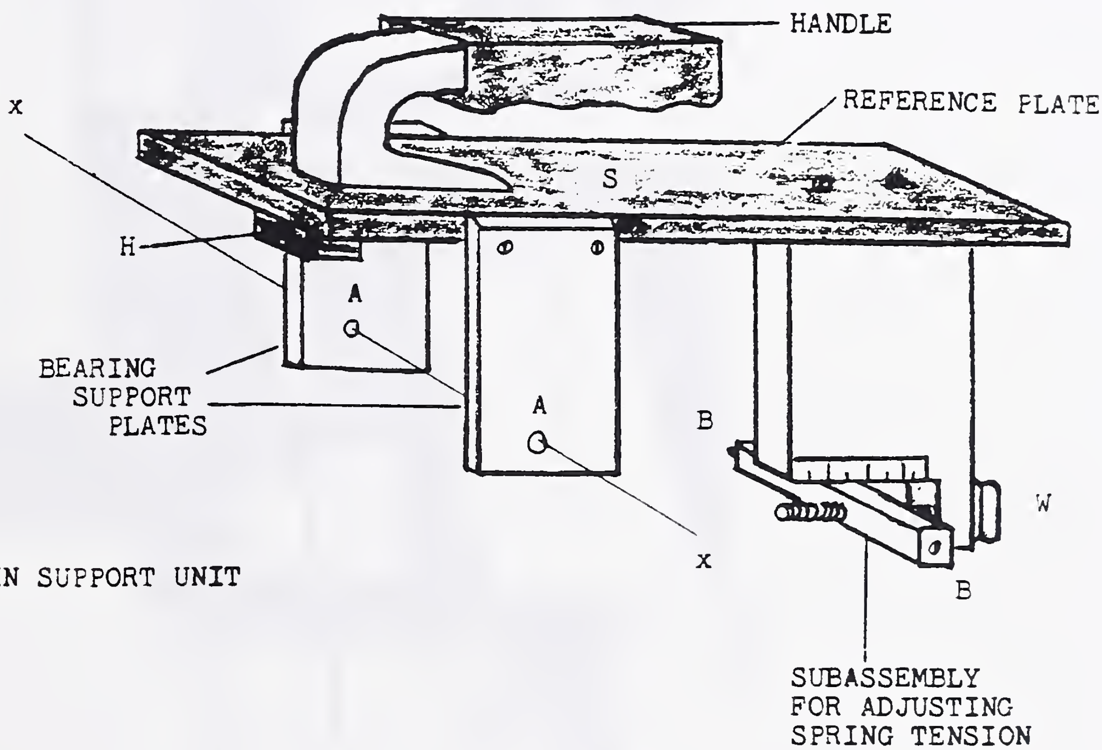


FIGURE 5. HUMAN SKIN CUT DATA FOR ALL TEST EDGES AT 20 POUNDS (89.0 NEWTONS)

(a) MOTOR SUBASSEMBLY





(b) MAIN SUPPORT UNIT

FIGURE 6. SCHEMATIC ILLUSTRATION OF INSPECTION DEVICE

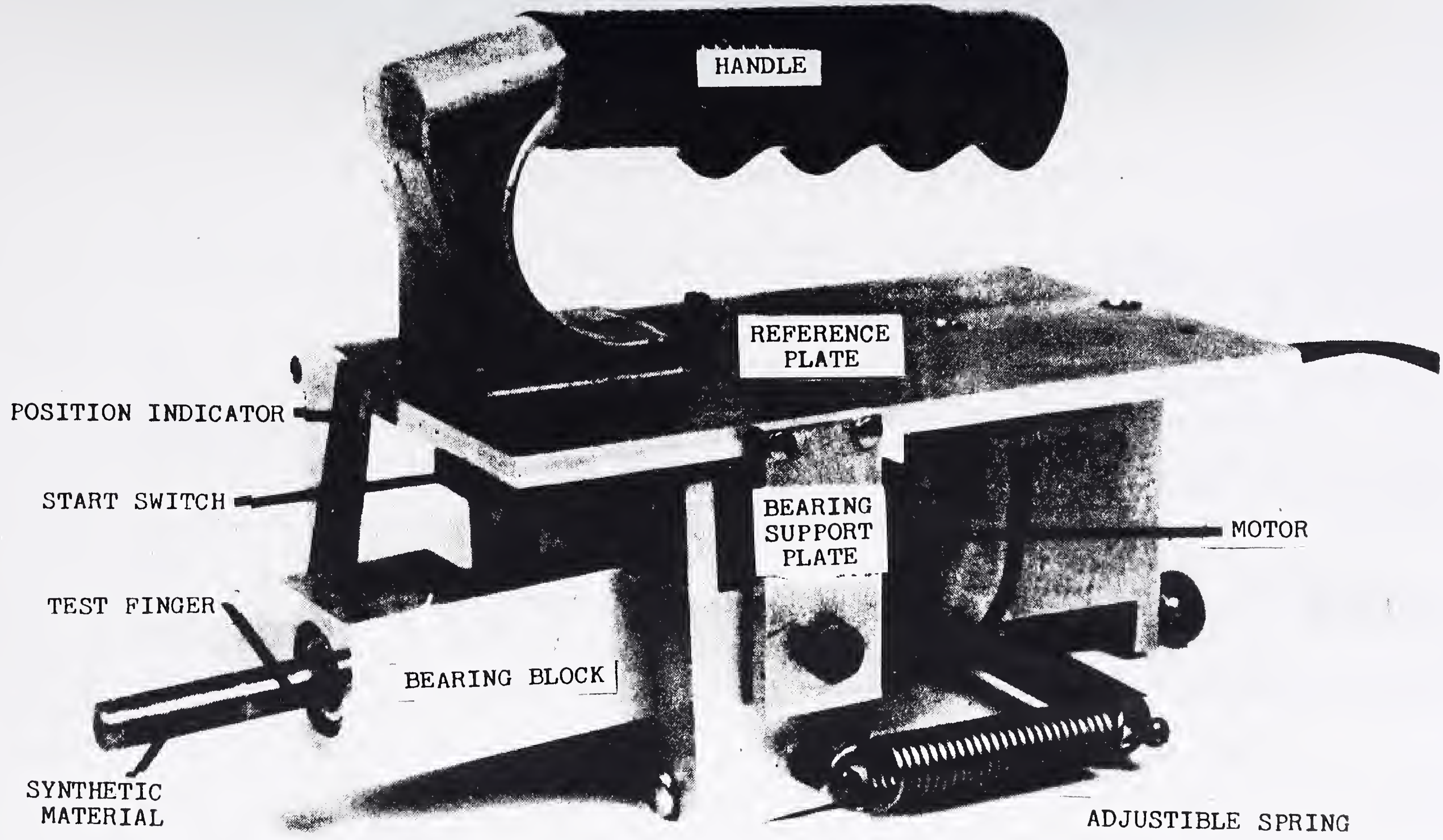


FIGURE 7. PHOTOGRAPH OF INSPECTION DEVICE

Figure 8. Force Settings for Edge Discriminations

Safety Criterion	"Safe" and "Hazardous" Test Edges	F_{LOW} (pounds)	F_{HIGH} (pounds)	Recommended Force Setting (pounds)
S_I (20 lbs, no break through epidermis)	Edge M "safe", all others "hazardous"	3.5 (15.6 N)	3.9 (17.3 N)	3.8 (16.9 N)
	Edges M and L "safe" all others "hazardous"	2.0 (8.9 N)	2.9 (12.9 N)	2.8 (12.4 N)
S_{II} (4 lbs, no complete penetration	Edge A "hazardous" all others "safe"	1.0+ (4.4 N)	1.1 (4.9 N)	1.1 (4.9 N)

+The device is accurate in the range 1 lb. (4.4 N) to 4.8 lb. (21 N)

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR74-428	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

An Inspection Procedure for Detecting Hazardous Edges

5. Publication Date

6. Performing Organization Code

7. AUTHOR(S)

John R. Sorrells; Robert E. Berger

8. Performing Organ. Report No. NBSIR74-428

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 4460502

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Consumer Product Safety Commission
5401 Westbard Avenue
Bethesda, Md. 20016

13. Type of Report & Period Covered: Progress

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Previous human skin cutting experiments, using a series of test edges, were extended to establish the safe and hazardous test edges for each of two safety criteria chosen by the Consumer Product Safety Commission. A poly(tetrafluoroethylene) tape was chosen as a suitable material which, when applied in a rotary mode to the test edges, would be completely penetrated by only those edges labelled hazardous. An inspection device, capable of turning the material through a single revolution while providing prescribed contact forces between the material and an edge, has been built. The selected synthetic material was tested with the device to find the force settings for discriminating between the safe and hazardous test edges of each safety criterion:

1. At a contact force of 3.8 pounds (16.9 newtons), this material is completely penetrated by only those test edges which are capable of breaking through the epidermis of human skin when the contact force is 20 pounds (89.0 N). This is the safety criterion for "exposed" edges on consumer products.

2. At a contact force of 1.0 pounds (4.4 N), this material is completely penetrated by only those test edges which are capable of completely penetrating human skin when the contact force is 4.0 pounds (17.8 N). This is the safety criterion for edges which may only be inadvertently contacted.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Consumer product safety; Edges, hazardous; Injury; Inspection of Edges; Safety; Skin, cutting; Synthetic materials, skin

18. AVAILABILITY

[X] Unlimited per Consumer Product Safety Commission 03/15/01

~~[X] For Official Distribution. Do Not Release to NTIS~~

[ ] Order From Sup. of Doc., U.S. Government Printing Office Washington, D.C. 20402, SD Cat. No. C13

[ ] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	23
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	